Refrigerant Flammability:
A New Application of the Opposed-flow Burner

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Due to concerns about the impact of chlorofluorocarbons (CFCs) on stratospheric ozone, new refrigerants are being evaluated by the air-conditioning and refrigeration industry to identify environmentally friendly replacements. These alternative refrigerants are primarily hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs), some of which, because of the additional hydrogen atoms, are flammable. In order to maintain the current building code requirement of non-flammable refrigerants, optimized mixtures which maximize efficiency while minimizing risk are desired. Current methods of measuring flammability of weakly flammable refrigerants have a large uncertainty and produce results which require operator interpretation. This work presents an alternative approach with reduced uncertainty and less subjectivity.

Traditionally, flammability has been measured by devices such as the ASTM E-681 5 liter flask[1] or the Bureau of Mines explosion tube.[2] These devices are operated by igniting a volume of premixed air and fuel, and evaluating whether or not flame propagation successfully occurs. The lean flammability limit is the ratio of fuel to air above which propagation occurs. These devices model a semi-realistic scenario of an ignited gas release. But from a testing perspective, they have significant drawbacks. Both are sensitive to the size, type, and location of the ignition source. In the Bureau of Mines device the difference between upward propagation and downward propagation adds ambiguity to the determination of an explicit flammability limit. Another disadvantage is that these test methods are sensitive to the test volume diameter. This measurement affects the flame propagation due to cooling at the vessel walls. The overriding

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disadvantage to these two devices is that a subjective determination is necessary to evaluate the indistinct boundary between propagation and non-propagation.

Though the goal of modeling a "realistic" scenario is admirable and for the purpose of risk assessment crucial, in a test where one is measuring the limiting fuel-to-air ratio of self-sustaining flammability, the result should be definitive and independent of an operator's interpretation, the ignition source, and the burner or test vessel. When these test methods are used with weakly flammable refrigerants, in comparison with hydrocarbon fuels, the difficulties are amplified due to the generally thicker flames and slower burning velocities.

For more than twenty years,[3] the opposed-flow burner has been used by combustion researchers to investigate properties of hydrocarbon flames. The opposed-flow burner used in this work contains two water-cooled, converging nozzles surrounded by a thin N_2 annulus. It supports a twin flame between two identical, vertically-aligned, opposed jets of premixed fuel and air. The flame condition is defined by the fuel/air equivalence ratio and the global strain rate. The global strain rate is the average exit velocity divided by half the nozzle separation. Extinction conditions are measured either by holding the strain rate constant, while reducing the equivalence ratio, or reducing the strain rate and holding the equivalence ratio constant. The zero strain extinction concentration can be linearly extrapolated from extinction concentration points for a range of low global strain rates. Based on work by Law et al.[4] with local velocity measurements and local strain rates, this value appears to correspond to the lean flammability limits of hydrocarbon fuels.

Using the global strain rate, this technique has been used to measure the lean limit of flammability for CH_2F_2 (difluoromethane or Refrigerant 32).[5] In Figure 1 a plot of multiple extinction points, Φ_x, for different global strain rates, K_g, for flames of CH_2F_2 in air are shown. Φ_x is defined based upon complete conversion of the carbon to CO_2 and the hydrogen and fluorine to HF for a stoichiometric mixture.

At the intercept, where $K_g = 0\ s^{-1}$, the lean flammability limit, $\Phi_o = 0.78 \pm 0.04$ is defined. The uncertainty reported here was calculated by reevaluating the intercept for 100 simulated data sets with a random error in the range of the flow calibration uncertainty added. The standard error of the intercept due to the extrapolation and linearity of the fit is an order of magnitude smaller, indicating that further improvements in calibration could significantly reduce the overall uncertainty in this determination the lean limit of a refrigerant fuel. By measuring extinction points rather than lack of ignition, and extrapolating to the fundamental limit, the opposed-flow burner eliminates several of the difficulties associated with the more traditional devices.

An additional challenge to the refrigeration industry is to determine the critical flammability ratios of mixtures of flammable and non-flammable refrigerants, that is, the amount of flammable refrigerant which can be added to a non-flammable refrigerant without making the mixture flammable. Preliminary results with mixtures of CH_2F_2 and C_2HF_5 indicate that a linear extrapolation of the maximum global strain rates for flammable mixtures with different ratios of flammable and non-flammable refrigerants to the zero strain condition provide a well defined and believable critical flammability ratio. Results from these tests will be reported.

Computational modeling of the combustion of a one dimensional, unstrained flame of CH_2F_2 in air, individually and in mixtures with CH_4, has been performed with the chemical kinetics code CHEMKIN using the mechanism for the methane/air chemistry from GRI[6] and for the F/C/H/O chemistry from Burgess et al.[7] Initial estimates of the laminar flame speed for CH_2F_2 from stoichiometric to lean flames will be presented and interpreted in light of the experimental results.

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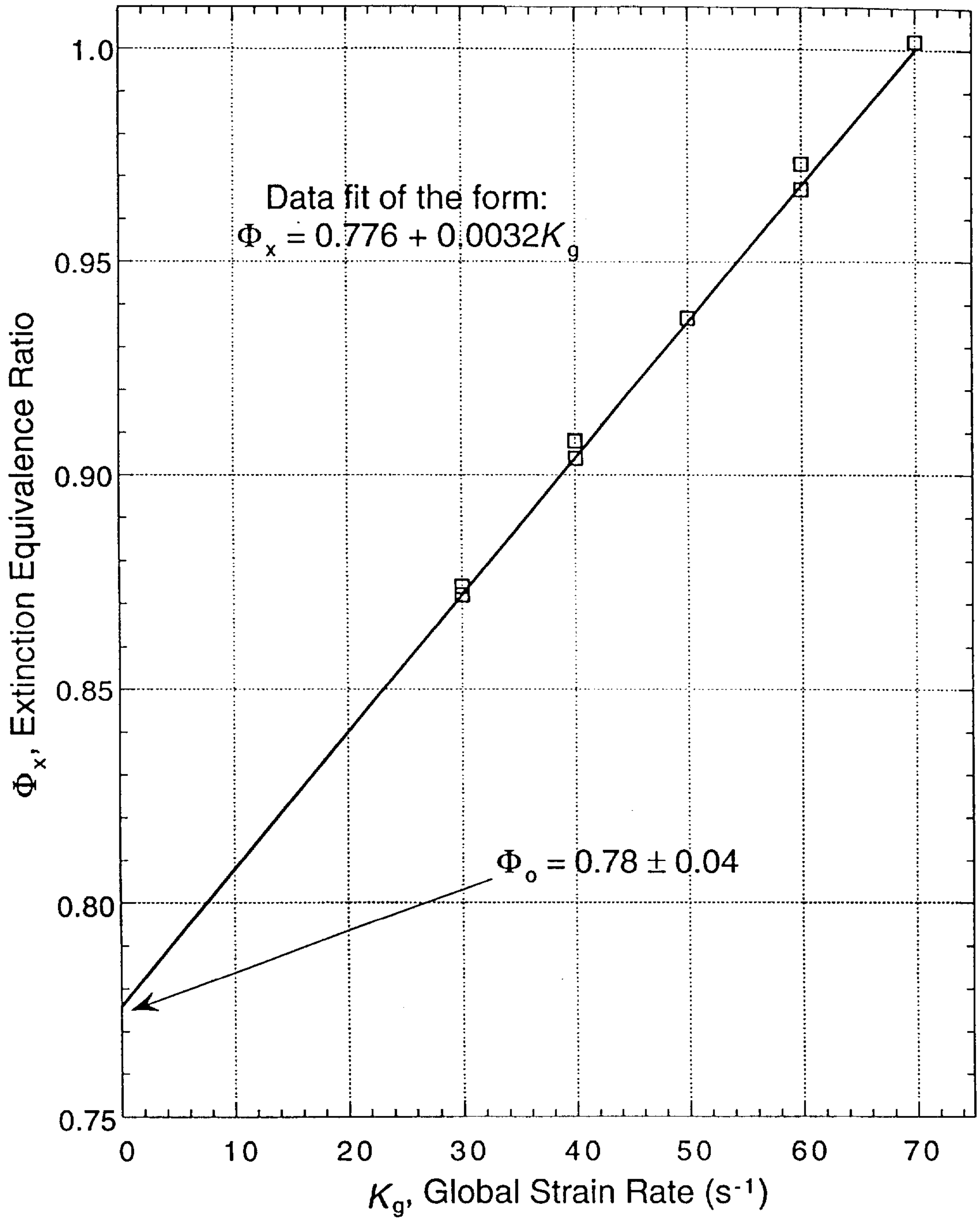

Figure 1: Lean extinction points and zero strain intercept for CH_2F_2 in dry air.